LWS TR&T Focus Team: Exploring the Magnetic Connection Between the Photosphere and Low Corona

Team Progress Report: Year 1, December 2009

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Team Chair:

- Alphonse Sterling

Team Members:

- William Abbett
- Na Deng
- Bart DePontieu
- Marc DeRosa
- Scott McIntosh
- Stephen White

1 Overview

Our group aims to explore the physical and magnetic connections between features in the solar photosphere and features at higher levels of the solar atmosphere, and their connections to heliosphere. Our group covers diverse topics such as solar spicules, magnetic fields, active regions, and wave propagation in the solar atmosphere. Our plan for the first year was to initiate individually the projects in our disparate specialties, with a view toward doing more focused and combined projects later in the program.

Very generally speaking, Drs. Abbett and Deng are carrying out theoretical and observational studies of active regions; Drs. De Pontieu and McIntosh are investigating wave propagation in the lower- and outer-atmosphere; Dr. DeRosa is studying interacting magnetic fields; and Drs. De Pontieu and Sterling are carrying out observational studies of spicules. So far the group's work has resulted in two papers accepted for publication, and several other papers are either submitted or in preparation for submission. A detailed summary of each member's progress follows further below.

2 Team Meeting

Our group has had two meetings:

- 2008 December 10, Napa, California. Held during the workshop on "Solar Activity During the Onset of Solar Cycle 24" meeting.
- 2009 June 15, Boulder, Colorado. Held during the 2009 meeting of the Solar Physics Division of the American Astronomical Society.

Due to logistical limitations, it was necessary to hold both of these meetings during concurrent scientific meetings. The next meeting however is planned as a separate stand-alone meeting, likely to be held in early 2010 in Boulder, Colorado.

3 Team Member Progress

3.1 W. Abbett

This study's goal is to understand the magnetic and energetic connection between the photosphere and corona as active regions emerge and evolve, and to determine the simplest means to describe quantitatively the system so that progress can be made in more realistically driving large scale models of the Sun-to-earth system. Over the past year, Dr. Abbett and colleagues have made significant progress toward this goal, and have met most of the stated first year objectives and milestones.

Research this past year has followed two parallel paths. The first involves the forward modeling of the combined convection zone-to-corona system, and the second involves the theoretical study of active region electric fields in the solar photosphere.

The modeling effort over the first year focused on extending the quiet Sun models of Abbett (2007, ApJ 665, 1469) to active region spatial scales. To achieve this objective, a number of technical challenges had to be addressed. Considerable effort went into updating and improving the 3D MHD code RADMHD to accommodate the physical and numerical challenges inherent in modeling active region magnetic fields in a computational domain that self-consistently includes both a turbulent convection zone and corona. An updated version of the code (v. 1.02) that includes all of the latest improvements to the development version of the code has been completed.

The second area of study involves the direct determination of electric fields and flows, from a sequence of vector magnetograms. The motivation for this effort is twofold: First, to determine an electric field that is consistent with both the observational data and the physics of Faraday's Law, and second, to understand better how magnetic energy is introduced into the corona from below the surface.

The standard way of quantifying the magnetic energy associated with an active region typically involves the reconstruction of the coronal field via non-linear force-free extrapolations. Energy estimates based on extrapolations however vary significantly between models, and so Abbett et al. have been working to obtain a more reliable, less model-dependent quantitative estimate of the Poynting flux independent of an extrapolation. This can be done by obtaining all three components of the electric field from sequential measurements of the photospheric field. Over the past year Drs. George Fisher and Bob Welsch have focused on this challenge, and have made significant progress. With partial support from this TR&T grant, they have developed the PTD (Poloidal-Toroidal Decomposition) technique that makes it possible to derive a 3D electric field from a time series of 2D vector magnetograms that obeys all three components of the Maxwell-Faraday equation. Since the electric fields on the solar surface can be determined, it is now possible to quantify the flux of magnetic energy and relative magnetic helicity into flare and CME-producing parts of the solar atmosphere. The PTD solution for the electric field however is not unique, and can differ from the true solution by the gradient of a potential function. Drs. Fisher and Welsch have also developed generalized variational and iterative techniques to specify the potential function. Working with Abbett and D. J. Bercik (cf. Abbett et al. 2004, ApJ, 612, 557), they have tested their technique with synthetic data sets, and obtained encouraging results.

A paper describing the testing of the PTD technique against synthetic data is in preparation for submission to the Astrophysical Journal. Work on all of these projects, along with extensions, will continue into the second year.

Deliverables: Dr. Abbett released an updated version of the modeling effort's public code (v. 1.02). He also hosted a one day RADMHD users workshop in association with the University of Michigan's CCHM team meeting.

3.2 N. Deng

The basic objective of this project is observational studies of active region magnetic fields and associated dynamics in the chromosphere.

Dr. Deng and colleagues are studying existing ASP (Advanced Stokes Polarimeter) full Stokes data in the Mg 517.27 nm line, which is formed in the low chromosphere (about 600 km above $\tau = 1$ level), including study of the asymmetric properties of the Stokes profiles and chromospheric Non-LTE Stokes inversions. They are to apply the techniques to new chromospheric Stokes observations taken by Hinode NFI (Na D and Mg lines), SOLIS or BBSO. After obtaining reliable chromospheric magnetic field vector data, those data will be used as a lower boundary condition to extrapolate 3D coronal magnetic fields and compare the results with coronal observations as well as with extrapolations using photospheric magnetic field as lower boundary condition.

During the first year, Deng and colleagues analyzed the Stokes asymmetries of the Mg 517.27 nm line. They also studied the velocities derived from Stokes I and Stokes V profiles, and compared the Stokes properties of the Mg line with those derived from photospheric lines observed simultaneously. They found significant differences between the Stokes properties for various regions. These differences hint at dramatic changes of the field inclination, strength, and plasma flows from the photosphere to the chromosphere. The derived asymmetric and dynamic properties of the observed Mg Stokes parameters also provide constraints for chromospheric Stokes inversions. They used a "Stokes Inversion based on Response functions" (SIR) code to invert the Mg Stokes data, as this code can take the observed Stokes asymmetries into account. They also used the inverted chromospheric magnetic field vector as a lower boundary condition to extrapolate the 3D coronal fields with non-linear force free extrapolation method. The result is different from those extrapolated using photospheric magnetic data. This work is summarized in two manuscripts, one in preparation and the other submitted. The in-preparation paper is: "Study of Stokes Parameters of Solar Active Region 9661 Using Simultaneous Observations of Photospheric FeI and Chromospheric MgI Lines," by Deng, Na, Choudhary, Debi Prasad, Balasubramaniam, K. S., & Solanki, Sami K.

Deliverables: Paper submitted to Solar Physics: "Formation of Chromospheric Infrared Emission Lines of Helium and Hydrogen," by Tejomoortula, Usha Sree, Choudhary, Debi Prasad, Rangarajan, K.E., Deng, Na, Penn, Matthew J., & Uitenbroek, Han.

3.3 B. De Pontieu

Dr. De Ponieu and co-workers have been focusing on two aspects of Alfvén waves in the chromosphere: using ground-based data from Hinode/SOT and the CRISP instrument (at the Swedish Solar Telescope) to determine the properties of transverse motions in the chromosphere, and using a combination of Hinode and CoMP data to investigate the mismatch between reported chromospheric and coronal Alfvén wave amplitudes.

The first part of the work involved identifying the disk counterparts of the type 2 spicules that have been discovered with Hinode at the limb (in Ca II H data). Following up on work done with IBIS data, they found that so-called rapid blue-shifted events (RBEs) in Ca 8542 spectra and images are most likely the disk counterparts of type 2 spicules. They also found these events in H-alpha and used this data to confirm that the observed motions at the limb are in fact real mass motions. The advantage of studying the disk counterpart is that line-of-sight superposition, which complicates the interpretation of images at the limb enormously, is not a significant problem. They developed an automated detection algorithm that finds RBE's, and have measured the transverse motions of a large number of these features for a variety of magnetic field environments (quiet Sun, equatorial coronal hole, and active region plage). This work is being prepared for publication and will be submitted to ApJ during the next few months. This work was done in close collaboration with no-cost collaborators at the University of Oslo.

The second part of the work involves a study exploiting the recent discovery by De Pointieu and collaborators of ubiquitous low-frequency (< 5 mHz) Alfvén waves in the solar chromosphere (with the Solar Optical Telescope on Hinode) and corona (with the ground-based Coronal multi-channel Polarimeter; CoMP) to try to determine the Alfvén wave energy content of the corona. They find that the apparent discrepancy in the resolved coronal Alfvén wave amplitude (~ 0.5 km s^{-1}) compared to that of the chromosphere ($\sim$ 10-20 km s^{-1}) can in principle be caused by the enormous line-of-sight superposition that is present in the optically thin corona. They developed a forward model to try to model how many different, independently oscillating threads are required to quench the amplitudes of order 10-20 km s^{-1} down to 0.5-1 km s^{-1} (as observed with CoMP). Their forward model predicts emission line widths that are invariant with time, which is exactly what CoMP observes. De Pontieu et al. investigate how phase mixing can reduce the number of required threads (within a CoMP pixel) from many hundreds down to less than one hundred. Independent of the forward model, and perhaps more significantly, they have discovered a direct relationship between the rms amplitudes of the low-frequency Alfvén waves (seen with CoMP) and the non-thermal line broadening of the coronal line that CoMP studies. This finding indicates that the process responsible for non-thermal line broadening of the coronal lines is directly coupled to low frequency Alfvén waves. They are still exploring the various possible scenarios that can couple these two observations, but it suggests that the corona really is riddled with Alfvén waves strong enough to accelerate the fast solar wind in magnetically open regions and heat the magnetically closed quiet corona. This work is being prepared for submission to ApJ letters or ApJ.

3.4 M. DeRosa

DeRosa and colleagues are studying the interaction between emerging magnetic flux and pre-existing coronal field by means of numerical simulations using the magneto-frictional method. By advancing the induction equation in time, the magneto-frictional method models the coronal magnetic field as a quasi-static sequence of non-linear force-free field configurations evolving in response to photospheric evolution. Such a scheme enables them to investigate the formation of current sheets, topological aspects of the series of field configuration, and relative magnetic helicity. Presently, they are applying this method to a series of snapshots from an advanced MHD simulation of an emergent flux structure.

3.5 S. McIntosh

McIntosh's study is titled: "Coronal Morphology - The Interplay of Structure and Energetics." He and colleagues have started on several parallel threads of work, analysis and interpretation of data from the Coronal Multi-Channel Polarimeter (CoMP) towards the goals of their project. While waiting to deploy CoMP to Haleakala Solar Observatory (HSO), they have been improving their Alfvén wave diagnostic tools, understanding the shortage of CoMP-resolved Alfvén wave power relative to that of Hinode, and developing Stokes profile forward modeling of the three dimensional coronal magnetic field.

In some more detail: McIntosh et al.'s original wave diagnostic analysis has been extended to real time-distance seismology, and they can now build k-omega diagrams of the oscillating structures in the corona (Tomczyk & McIntosh 2009). These structures show dispersionless waves traveling outward and inward with the same phase speed, but very unequal power ratios that vary radially from the limb and are correlated to growths of the observed non-thermal line broadening that possibly indicate significant Alfvén wave dissipation in the corona. The wave direction and phase-speed diagnostics developed will be combined with Stokes V measurements (and forward modeling) to constrain the coronal vector magnetic field.

In partnership with De Pontieu, McIntosh has been working to understand the shortfall in resolved CoMP wave power relative to that seen in spicules by Hinode. They developed a forward model of oscillating threads in the corona, driven by chromospheric spicules, showing that the observed non-thermal line broadening of Fe XIII 10747 Å amplitude is the transverse amplitude of the Alfvén waves in the corona, which under significant line-of-sight superposition quench the resolved velocity amplitude of CoMP. This work, in preparation for submission to Science magazine, also allows them to address the voracity of the waves observed by CoMP as being Alfvénic and less likely to be "Kink" modes, or "torsional" Alfvén waves due to the expected sparse filling of the corona with the latter.

McIntosh, with assistance Co-I Dr. Leamon, have been adapting high-resolution PFSS coronal magnetic models to work with the approach of Judge et al. 2006 ("Spectral Lines for Polarization Measurements of the Coronal Magnetic Field. IV. Stokes

Signals in Current-carrying Fields," ApJ, 651, 1229). They will synthesize Stokes profiles for the corona in 10747 Å, with the hope that an inversion strategy can be developed from this approach to deliver magnetic field characteristics in the plane-of-the-sky that can be constrained by the other diagnostics provided by CoMP, such as line-of-sight electron density and Alfvén wave diagnostics.

In the coming year they hope to complete the Stokes forward model code, analyze the new CoMP observations from Hawaii using this new diagnostic in concert with the Fe XIII IR density diagnostics, Alfvén wave diagnostics, constructing wave power maps and vector-field maps of the corona in the plane of the sky utilizing the Stokes-V/Wave approach. The latter can be verified with the forward-model, with luck.

Deliverables: Tomczyk, S. & McIntosh, S.W., 2009, "Time-Distance Seismology of the Solar Corona with CoMP," in press ApJ; http://arxiv.org/abs/0903.2002.

3.6 A. Sterling

Sterling's general objective is to obtain a better understanding of solar spicules. During the first year, his main project was to examine a high-cadence data set from the Hinode Solar Optical telescope (SOT), observing a polar coronal hole region of the Sun. A particularly appropriate data set was found from 2007 July 25, as it had images in Ca II at 10 sec cadence. Sterling and colleagues constructed a continuous 70-minute long movie of these images. They processed the images using a point spread function (PSF) for SOT Ca II images derived by Dr. Craig DeForest; using this filter made it was possible to see spicules near the limb but still on the disk, allowing them to see with increased clarity the origin of some of the spicules, and for some of the spicules they were able to follow the long-term evolution after ejection from the solar surface. The specific features they observed are referred to as "Type II" spicules by De Pontieu et al. (2007, PASJ, 59, S655).

They found that the source region of the spicules corresponds to locations of apparent-fast-moving ($\sim$ few $\times$ 10 km s^{-1}), transient (few $\times$100 sec), Ca II brightenings on the disk. Frequently the spicules occur when these brightenings appear to collide and disappear. After ejection, when seen above the limb, many (if not all) of the spicules fade by expanding laterally (i.e., roughly transverse to their motion away from the solar surface), often splitting into two or more spicule "strands," and the spicules then fade without showing any downward motion. Photospheric/chromospheric acoustic shocks alone likely cannot explain the high velocities ($\sim$ 100 km s^{-1}) of the resulting spicules.

These observations give new insights into the origin of the Type II spicules. If the Ca II brightenings represent magnetic elements, then reconnection among those elements may be a candidate to explain the spicules. Alternatively, many of the spicules could be small-scale magnetic eruptions, analogous to CMEs, and the apparent fast motions of the Ca II brightenings could be analogs of flare loops heated by magnetic reconnection in these eruptions.

This work has been summarized in a Letter to the Astrophysical Journal.

Deliverables: "*Hinode* SOT Observations of the Source Regions and Evolution of "Type II" Spicules at the Solar Polar Limb," by Alphonse C. Sterling, Ronald L. Moore, & Craig E. DeForest. ApJ Letters 2010, in press.

3.7 S. White

No report available.